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### (54) Catadioptric lens system

(57) A catadioptric lens system whose entire size is practically compact and is capable of providing a large numerical aperture in the ultraviolet band region is disclosed. The invention also provides photolithographic resolution of quarter micron levels and is easy to manufacture. The invention comprises, a first lens system S1 constructed with refractive members, a concave mirror M1, and a second lens system S2 constructed with refractive members to project a semiconductor device pattern from a reticle surface onto a substrate wherein at least said first lens system includes one or more aspherical surface(s) which point to the reticle surface.

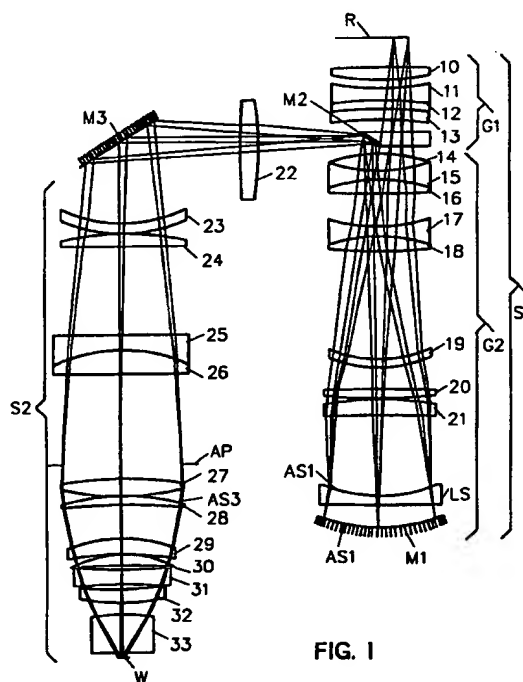


FIG. 1

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## Description

## BACKGROUND OF THE INVENTION

5 The present invention relates to the lens system in a projection exposure apparatus used for manufacturing semiconductor devices or liquid crystal devices and the like via photolithographic processing. The invention specifically relates to a catadioptric lens system which is capable of providing a photolithographic resolution of quarter micron levels in the ultraviolet band region by using a reflective mirror as an element of the lens system.

10 In photolithographic processing for manufacturing semiconductor devices and the like, a projection exposure apparatus is used in which a semiconductor device pattern printed onto a photomask or reticle (hereafter both are referred to as reticle) is exposed via a projection lens system onto a substrate such as a wafer or glass plate (hereafter both are referred to as a wafer) coated with photoresist and the like. As integration of semiconductor devices and the like advances, demand for a projection lens system used in projection exposure apparatus requiring more stringent resolution increases. In order to fulfill this need, using a shorter band illumination light and using a larger numerical aperture (NA) for a projection lens system have become essential. Various technologies have been proposed in order to meet the requirement in which a projection lens system is constructed with a so called "catadioptric lens system" which is a combination of a reflective system and a refractive system.

For example, Japanese patent kokai S63-163319 and kokai H5-25170 disclose a catadioptric lens system which uses an exposure region including light on the optical axis.

20 In addition, kokai H7-111512 and US 4,779,966 use light on the exposure region of a ring field, rather than light on the optical axis.

In the catadioptric lens system using an exposure region which includes light on the optical axis, a beam splitter having a transmissive reflective surface is required for splitting the optical path. This lens system may easily generate light aberrations, causing flares or uneven illumination on the surface of a wafer. These light aberrations are generated from internal reflections from the wafer surface, from a refractive surface of the lens systems arranged behind the beam splitter, or from the transmissive reflective surface of a beam splitter and the like. A lens system with a larger numerical aperture requires a larger beam splitter and a longer exposure time due to the decrease in light intensity. This in turn, causes a decrease in throughput of the semiconductor manufacturing process. Also, as disclosed in Japanese patent kokai H6-300973, a reflection beam splitter is required to prevent loss of light intensity, however, it is very difficult to manufacture a large reflection beam splitter and its use gives unfavorable imaging performance due to the uneven film thickness of the transmissive reflective layer, which affects the deflection, absorption, and phase change of the light, etc.

30 On the other hand, in the catadioptric lens system disclosed in US 4,779,966 using a ring exposure field, a reflective lens system is employed on the reduced side toward a wafer surface rather than at an interim image. However, the NA is larger on the reduced side than on the reticle surface side. It is difficult to split the optical path, making it impossible to increase the NA of the lens system. This does not provide excellent resolution. The size of the concave mirror cannot be increased either.

In the catadioptric lens system disclosed in Japanese patent kokai H7-111512 using a ring exposure field, the first lens system including a concave mirror for forming an interim image is constructed with a lens system in perfect symmetry, and the size of the interim image remains the same as the real size of the reticle surface. In this way, the possibility of generating aberrations in the first imaging lens is reduced, however, this gives a heavier load onto the second imaging lens system. Especially, when a large NA is required for the lens system, it is inevitable that the size and complexity of the second lens system must be increased.

45 The present invention intends to resolve the problem by providing a catadioptric lens system whose entire size is essentially compact and is capable of providing a large numerical aperture in the ultraviolet band region to obtain the photolithographic resolution of quarter micron levels and is constructed with components of reduced sizes.

## SUMMARY OF THE INVENTION

50 In order to accomplish the above object, the present invention provides a catadioptric lens system characterized by the fact that the catadioptric lens system comprises:

- a) a first lens system S1 constructed with refractive members,
- b) a concave mirror M1, and
- c) a second lens system S2 including refractive members to project a semiconductor device pattern from a reticle surface onto a substrate wherein at least said first lens system S1 includes one or more aspherical surface(s) which point to the reticle surface.

The invention further relates to a catadioptric lens system comprising:

- a) a first lens system constructed with refractive members,  
 b) a concave mirror, and  
 c) a second lens system constructed with refractive members to project a semiconductor device pattern from a reticle surface onto a substrate wherein at least one of the refractive members in the first lens system has at least two different negative refractive powers and wherein another refractive member has at least two different positive refractive powers.

Moreover, the catadioptric lens system of the present invention is further characterized by a) a first lens system constructed with refractive members,  
 b) a concave mirror, and c) a second lens system constructed with refractive members to project a semiconductor device pattern from a reticle surface onto a substrate wherein the first lens system comprises:

a first lens group in which light enters only once and a second lens group through which light makes a round trip. The lens closest to the concave mirror of the second lens group in the first lens system is a negative lens. Light coming through the second lens group images the semiconductor device pattern once before entering the second imaging lens system.

#### BRIEF DESCRIPTION OF THE DRAWINGS

- Figure 1 shows a layout of a catadioptric lens system of embodiment 1.  
 Figure 2 shows an aberration diagram of a catadioptric lens system of embodiment 1.  
 Figure 3 shows a layout of a catadioptric lens system of embodiment 2.  
 Figure 4 shows an aberration diagram of a catadioptric lens system of embodiment 2.

#### BRIEF DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the present embodiment, as described, the chance of generating aberrations of high orders is reduced and the NA of the lens system is increased, thus preventing an increase in the complexity and size of the lens system. Changing the refractive surface from a spherical surface ideally bends light flux which exists around the lens surface. This makes it possible to correct aberrations of high orders without broadening the entire flux.

Introducing aspherical refractive surfaces to the first lens system S1, prevents increasing the size of it. Introducing aspherical refractive surfaces to the second lens system S2, also prevents increasing the size of it.

Also, it is preferable that the first lens system S1 comprises a first lens group G1, in which light enters only once and a second lens group G2 in which light makes a round trip. The lens closest to the concave mirror M1 of the second lens group G2 is a negative lens LS. Light coming through the second lens group G2 images a semiconductor device pattern once before entering the second lens system S2. This configuration of the lens system especially allows decreasing the size of each of its component members. In addition, the configuration is very effective in reducing chromatic aberration on the axis wherein the configuration includes, in order in which light progresses, a negative lens LS which is closest to the concave mirror M1 in the second lens group G2, a concave mirror M1, and the second lens system S2 wherein the semiconductor device pattern is imaged once before light emitted from the second lens group G2 enters the second lens system S2.

In the lens system of the aforementioned configuration, it is preferable that the second lens group G2 is constructed with a refractive member having at least two different negative refractive powers and a refractive member having at least two different positive refractive powers. The lens having negative refractive powers is effective in correcting coma or spherical aberrations and image curvature and the like. The lens having positive refractive powers is effective in not increasing the size of the lens system and provides a large NA or exposure region. Moreover, it is desirable that each of the members have at least two lenses in order to reduce the load for correcting aberrations of the second lens system S2.

Also, it is preferable that the first lens group G1 is constructed with refractive members having three different refractive powers. Lately, as the demand for higher resolution increases, more stringent specifications are demanded for correcting distortion, image curvature and the like. It is important for one to adjust these parameters during manufacturing to meet this demand. These adjustments for a lens positioned in the vicinity of the reticle surface work effectively. The second lens group G2 of the present invention, is the lens system for both outgoing and incoming light, which is inappropriate for adjustment lenses. For this reason, constructing the first lens group G1 with lenses having at least three different refractive powers makes it possible to adjust distortion or curvature aberration during manufacturing of lens systems. Also, by utilizing the first lens group G1 in the aforementioned configuration, the working distance in the vicinity of the surface of the reticle R can be increased and a step and scan method of exposure is made possible.

The second lens system S2 plays an important role in correcting mainly spherical or coma aberrations to allow the

lens system to have a large NA.

In the present invention, it is preferable to arrange a second optical path reflection member M3 between the first lens system S1 and the second lens system S2 or in the second lens system S2. Also, it is possible to dispose the reflection member M3 in the second imaging lens system. By installing an optical path reflection member such as a mirror, the entire lens system can be bent, reducing its entire size.

Short band wavelengths, in excess of 300nm, are used as the light source in the present invention, therefore, quartz or fluorite are preferable as the material for a refraction member. These minerals are excellent in illumination transmissivity, they are inexpensive, and they are easy to process.

Also in the present invention, the concave mirror M1 can be formed aspherically. If a concave mirror M1 is aspherical, the magnitude of the positive refractive power of the concave mirror M1 can be increased without generating aberrations of high orders which makes it possible to manufacture compact lens systems having a large NA and also allows correcting chromatic aberration over a wide bandwidth.

Note that by forming an aperture stop (variable aperture) in the optical path of the second lens system S2, the coherence factor ( $\sigma$  value) can be adjusted. A technique to increase focal depth and improve resolution is disclosed for example in Japanese patent kokai S62-50811 in which a phase shift technique is used to shift the phase of a predetermined portion of the reticle pattern from another portion. The present invention provides increased effect of the phase shift technique with adjustment of the coherence factor ( $\sigma$  value).

The examples expressed quantitatively for the catadioptric lens system of the present invention are shown herein. The catadioptric lens system in each of the quantitative embodiments comprises, in order from the reticle R side (in the order that light progresses):

- a) a first lens system S1 constructed with refractive members,
- b) a concave mirror M1, and
- c) a second lens system S2 constructed with refractive members to project a semiconductor device pattern from a reticle surface onto a substrate wherein at least one of the refractive members is arranged between the first lens system S1 and the second lens system S2; the first lens system S1 comprises a first lens group G1 through which light goes through only once and the second lens group G2 through which light makes a round trip. The lens closest to the concave mirror M1 in the second lens group G2 of the first lens system is a negative lens LS.

NA=0.6 in each of the quantitative embodiments, and aberrations for the image height are corrected within the range of about 5 to about 18.6. Note that the range for the aforementioned image height may be a ring field or may be a rectangle of 6 x 30 at a distance of 5 from the optical axis.

In each of the tables in embodiments 1 and 2,  $r$  denotes surface curvature radius and  $d$  denotes a distance between surfaces. Glassy materials are denoted as  $\text{SiO}_2$  for quartz and  $\text{CaF}_2$  for fluorite in each of the tables. The refraction rates for quartz and fluorite for  $n$ , at 193.0 nm, and for  $1/\nu$ , which is the dispersion value for those of  $\pm 0.1\text{nm}$ , are as follows:

	$n$	$1/\nu$
synthetic quartz:	1.56019	1780
fluorite	1.50138	2550

In each of the embodiments, an aspherical surface is shown by the following equation where:

- Z: distance from the top measured in the direction of the optical axis.
- Y: distance from the top measured in the direction perpendicular to the optical axis.
- K: constant of the cone.
- $r$ : curvature radius of the top.
- $C_4, C_6, C_8, \dots$ : constants for 4-order, 6-order, 8-order aspherical surface.

$$Z = (Y^2 / r) / [1 + \sqrt{1 - (1 + K) Y^2 / r}] + C_4 Y^4 + C_6 Y^6 + C_8 Y^8 + C_{10} Y^{10} + C_{12} Y^{12}$$

In the first embodiment 1, a first lens group G1 comprises, in order from the side of the surface of the reticle R, a biconvex lens 10, a biconcave lens 11, a meniscus lens 12 whose convexity points to the side of the surface of the reticle R,

icle R, and parallel plane plates 13. The second lens group comprises, in order from the surface of the reticle R, a biconvex lens 14, a biconcave lens 15, a biconvex lens 16, a biconcave lens 17, a biconvex lens 18, a meniscus lens 19 whose concavity points to the side of the surface of the reticle R, a biconvex lens 20, a meniscus lens 21 whose convexity points to the side of the surface of the reticle R, and a negative meniscus lens LS whose concavity points to the surface of the reticle R and is formed with an aspherical surface AS1 on the side of the reticle R. Parallel plane plates 13 in the first lens group G1 comprise a plan mirror M2 which is made by polishing a part of the lens to function as a first optical path reflection member M2. The image of the reticle R is formed once in the vicinity of the plane mirror M2. Also in the present embodiment, the concave mirror M1 is formed on an aspherical surface AS2.

In addition, the second lens system S2 comprises, in order from the surface of the reticle R, a biconvex lens 22 (which can be arranged in the second lens system S2 or can be arranged between the first and second lens systems S1 and S2 respectively), a meniscus lens 23 whose concavity points to the side of the surface of the reticle R, a biconvex lens 24, a meniscus lens 25 whose convexity points to the side of the surface of the reticle R, a biconvex lens 26, an aperture stop AP, a biconvex lens 27, a meniscus lens 28 formed with an aspherical surface AS3 whose convexity points to the surface of the reticle R, a meniscus lens 29 whose convexity points to the side of the surface of the reticle R, a meniscus lens 30 whose convexity points to the side of the surface of the reticle R, a biconcave lens 31, a meniscus lens 32 whose concavity points to the side of the surface of the reticle R, and a meniscus lens 33 whose convexity points to the side of the surface of the reticle R. Now, in the present embodiment, a plane mirror M3 is arranged optically between the first lens 22 and the second lens 23 of the second lens system S2 or in the second lens system S2 such that surfaces of a reticle R and a wafer W are arranged in parallel.

	Surface	r	d	Glassy material	R	
5	No.	0.000	50.000		S1	G1
	1	1827.099	25.000	SiO <sub>2</sub>		
	2	-391.019	13.420			
	3	-396.812	25.000	SiO <sub>2</sub>		
10	4	829.284	1.000			
	5	459.609	25.000	SiO <sub>2</sub>		
	6	745.296	1.000			
	7	488.042	25.000	SiO <sub>2</sub>		
15	8	586.033	25.000			
	9	0.000	35.000	SiO <sub>2</sub>		
	10	0.000	16.000			
	11	361.664	32.175	CaF <sub>2</sub>		G2
20	12	-449.989	1.000			
	13	-561.169	20.000	SiO <sub>2</sub>		
	14	255.230	1.000			
	15	223.249	39.738	CaF <sub>2</sub>		
25	16	-756.196	57.483			
	17	-315.859	20.000	SiO <sub>2</sub>		
	18	299.543	1.000			
	19	260.236	32.584	CaF <sub>2</sub>		
30	20	-675.594	211.188			
	21	-163.356	20.000	SiO <sub>2</sub>		
	22	-252.267	38.241			
	23	2280.139	25.000	SiO <sub>2</sub>		
35	24	-1082.014	3.367			
	25	556.937	40.000	SiO <sub>2</sub>		
	26	4236.526	156.695			
	27	-215.826	25.000	SiO <sub>2</sub>	LS	AS1
40	28	-4417.336	33.561			

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	29	-354.342	-33.561		M1	AS2
	30	-4417.336	-25.000	SiO <sub>2</sub>	LS	
	31	-215.826	-156.695			AS1
5	32	4236.526	-40.000	SiO <sub>2</sub>		
	33	556.937	-3.367			
	34	-1082.014	-25.000	SiO <sub>2</sub>		
	35	2280.139	-38.241			
10	36	-252.267	-20.000	SiO <sub>2</sub>		
	37	-163.356	-211.188			
	38	-675.594	-32.584	CaF <sub>2</sub>		
	39	260.236	-1.000			
15	40	299.543	-20.000	SiO <sub>2</sub>		
	41	-315.859	-57.483			
	42	-756.196	-39.738	CaF <sub>2</sub>		
	43	223.249	-1.000			
	44	255.230	-20.000	SiO <sub>2</sub>		
20	45	-561.169	-1.000			
	46	-449.989	-32.175	CaF <sub>2</sub>		
	47	361.664	-5.000			
	48	0.000	235.151		M2	
25	49	687.782	30.000	SiO <sub>2</sub>	S2	
	50	-1403.174	170.000			
	51	0.000	-150.026		M3	
	52	262.520	-25.000	SiO <sub>2</sub>		
30	53	474.401	-1.304			
	54	-632.711	-27.786	SiO <sub>2</sub>		
	55	5490.382	-168.081			
	56	-1783.259	-25.000	SiO <sub>2</sub>		
	57	-321.439	-4.402			
35	58	-357.850	-44.750	CaF <sub>2</sub>		
	59	3152.678	-173.787			
	60	0.000	-28.467		AP	
	61	-566.009	-45.000	CaF <sub>2</sub>		
40	62	806.950	-1.000			
	63	-212.463	-31.096	CaF <sub>2</sub>	AS3	
	64	-368.988	-65.190			
	65	-260.201	-44.295	SiO <sub>2</sub>		
45	66	-544.105	-1.000			
	67	-169.071	-31.373	CaF <sub>2</sub>		
	68	-824.497	-9.524			
	69	1558.569	-30.000	SiO <sub>2</sub>		
50	70	-466.123	-8.738			
	71	7503.078	-29.965	SiO <sub>2</sub>		
	72	566.609	-15.714			

73	-197.683	-64.000	SiO <sub>2</sub>
74	-1633.285	-17.000	
75	0.000		W

The units "r" and "d" are in millimeters (mm).

Constant of the cone, K, and aspherical surface constant, C

	AS1	AS2	AS3
	r 27 (=r31)	r29 (M1)	r63
K	0.000000	0.000000	0.000000
C <sub>4</sub>	$0.184947 \times 10^{-8}$	$0.820832 \times 10^{-9}$	$0.184651 \times 10^{-8}$
C <sub>6</sub>	$0.211178 \times 10^{-12}$	$0.447187 \times 10^{-13}$	$0.427327 \times 10^{-13}$
C <sub>8</sub>	$-0.382898 \times 10^{-17}$	$-0.564120 \times 10^{-18}$	$-0.101914 \times 10^{-17}$
C <sub>10</sub>	$0.152790 \times 10^{-21}$	$0.229674 \times 10^{-22}$	$-0.159307 \times 10^{-22}$
C <sub>12</sub>	$-0.561578 \times 10^{-26}$	$-0.558227 \times 10^{-27}$	$0.167653 \times 10^{-26}$

As described above, the required parameters comprise a NA of 0.6, the image height Y of 18.6, and the diameter of about 20 for all optical members of the catadioptric lens system. Figure 2 shows a horizontal aberration diagram for the catadioptric lens system of the present embodiment. Aberrations are measured for each bandwidth using the image height Y = 18.6 for (a) and Y = 5 for (b) with the unit Y in millimeters (mm). As is clear from Figure 2, aberrations are corrected very well by the reflective-refractive optical system of the present embodiment.

In the second embodiment 2, a first lens group G1 of the first lens system comprises, in order from the surface of the reticle R, a meniscus lens 34 whose convexity points to the side of the surface of the reticle R, a biconvex lens 35, a biconcave lens 36, a meniscus lens 37 whose convexity points to the side of the surface of the reticle R, and parallel plane plate 38. The second lens group G2 of the first lens system comprises, in order from the surface of the reticle R, a biconvex lens 39, a meniscus lens 40 whose concavity points to the side of the surface of the reticle R, a biconvex lens 41, a meniscus lens 42 whose convexity points to the side of the surface of the reticle R, biconcave lens 43, biconvex lens 44, a meniscus lens 45 whose convexity points to the side of the surface of the reticle R, a biconvex lens 46, a meniscus lens 47 whose concavity points to the side of the surface of the reticle R, and a negative meniscus lens LS whose concavity points to the surface of the reticle R. Parallel plane plates in the first lens group G1 comprises a plane mirror M2 which is made by polishing a surface of the lens to function as an optical reflection member. The image of the reticle R is formed once in the vicinity of the plane mirror M2. Also in the present embodiment, the concave mirror M1 is formed on an aspherical surface AS2.

In addition, the second lens system S2 comprises, in order from the surface of the reticle R, a biconvex lens 48, a meniscus lens 49 whose convexity points to the side of the surface of the reticle R, (the biconvex lens 48 and the meniscus lens 49 may be arranged within the second lens system S2 or between the first and second lens systems S1 and S2 respectively), meniscus lens 50 whose convexity points to the side of the surface of the reticle R, a meniscus lens 51 whose concavity points to the side of the surface of the reticle R, an aperture stop P, a biconvex lens 52 whose surface on the side of the reticle R is formed with an aspherical surface AS2, a meniscus lens 53 whose convexity points to the side of the surface of the reticle R, a biconcave lens 54, a meniscus lens 55 whose convexity points to the side of the surface of the reticle R, a meniscus lens 56 whose convexity points to the side of the surface of the reticle R, and a biconvex lens 57. Now, in the present embodiment, a plane mirror M3 is arranged between the lens 49 and the lens 50 in the second lens system S2 such that surfaces of a reticle R and a wafer W are arranged in parallel.



	Surface	r	d	Glassy , material		
5	No.	0.000	45.000		R	
	1	281.775	18.000	SiO <sub>2</sub>	S1	G1
	2	195.859	1.598			
	3	196.715	40.418	SiO <sub>2</sub>		
10	4	-480.361	14.536			
	5	-548.718	20.000	SiO <sub>2</sub>		
	6	204.428	5.448			
	7	203.274	20.000	SiO <sub>2</sub>		
15						
20						
25						
30						
35						
40						
45						
50						
55						

	8	401.273	25.000			
	9	0.000	35.000	SiO <sub>2</sub>		
5	10	0.000	15.500			
	11	303.555	30.000	CaF <sub>2</sub>		G2
	12	-1740.057	5.924			
	13	-425.354	20.000	SiO <sub>2</sub>		
10	14	-2761.815	1.849			
	15	300.937	40.000	CaF <sub>2</sub>		
	16	-2581.928	1.849			
	17	288.864	20.000	SiO <sub>2</sub>		
15	18	177.975	57.224			
	19	-175.888	20.000	SiO <sub>2</sub>		
	20	764.840	0.500			
	21	342.881	36.406	CaF <sub>2</sub>		
	22	-329.279	48.341			
20	23	270.936	25.000	SiO <sub>2</sub>		
	24	328.277	66.732			
	25	778.307	40.000	SiO <sub>2</sub>		
	26	-518.576	15.753			
25	27	-223.579	25.000	SiO <sub>2</sub>		
	28	-658.513	42.435			
	29	-229.025	25.000	SiO <sub>2</sub>	LS	
	30	-1514.955	17.542			
	31	-332.936	-17.542		M1	AS1
30	32	-1514.955	-25.000	SiO <sub>2</sub>	LS	
	33	-229.025	-42.435			
	34	-658.513	-25.000	SiO <sub>2</sub>		
	35	-223.579	-15.753			
35	36	-518.576	-40.000	SiO <sub>2</sub>		
	37	778.307	-66.732			
	38	328.277	-25.000	SiO <sub>2</sub>		
	39	270.936	-48.341			
40	40	-329.279	-36.406	CaF <sub>2</sub>		
	41	342.881	-0.500			
	42	764.840	-20.000	SiO <sub>2</sub>		
	43	-175.888	-57.224			
45	44	177.975	-20.000	SiO <sub>2</sub>		
	45	288.864	-1.849			
	46	-2581.928	-40.000	CaF <sub>2</sub>		
	47	300.937	-1.849			
	48	-2761.815	-20.000	SiO <sub>2</sub>		
50	49	-425.354	-5.924			
	50	-1740.057	-30.000	CaF <sub>2</sub>		
	51	303.555	-0.500			

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	52	0.000	233.000		M2
	53	415.207	31.117	CaF <sub>2</sub>	S2
5	54	-631.341	0.500		
	55	306.049	20.000	SiO <sub>2</sub>	
	56	218.635	150.000		
	57	0.000	-165.240		M3
10	58	-711.482	-25.000	SiO <sub>2</sub>	
	59	-2123.013	-302.795		
	60	3482.765	-30.000	SiO <sub>2</sub>	
	61	654.764	-15.000		
15	62	0.000	-59.904		AP
	63	-230.331	-70.000	CaF <sub>2</sub>	AS2
	64	1603.607	-0.500		
	65	-204.918	-28.538	SiO <sub>2</sub>	
20	66	-602.518	-14.615		
	67	1240.449	-30.000	SiO <sub>2</sub>	
	68	-510.567	-0.500		
	69	-308.492	-70.000	SiO <sub>2</sub>	
25	70	-714.386	-0.500		
	71	-170.397	-45.000	SiO <sub>2</sub>	
	72	-62.983	-4.156		
	73	-63.147	-62.343	SiO <sub>2</sub>	
30	74	766.887	-17.000		
	75	0.000			W

Constant of the cone, K, and aspherical surface constant, C

	AS1	AS2
	r 31 (M1)	r63
K	0.000000	0.000000
40 C <sub>4</sub>	0.815186 x 10 <sup>-9</sup>	0.371510 x 10 <sup>-8</sup>
C <sub>6</sub>	0.106110 x 10 <sup>-13</sup>	0.507303 x 10 <sup>-13</sup>
C <sub>8</sub>	0.216157 x 10 <sup>-18</sup>	0.416256 x 10 <sup>-18</sup>
C <sub>10</sub>	-0.473987 x 10 <sup>-23</sup>	0.261764 x 10 <sup>-22</sup>
45 C <sub>12</sub>	0.490366 x 10 <sup>-27</sup>	-0.397276 x 10 <sup>-27</sup>

As described above, the required parameters comprise a NA of 0.6, an image height Y of 18.6, and a diameter of about 20 for all optical members of the catadioptric lens system. Figure 4 shows a horizontal aberration diagram for the catadioptric lens system of the present embodiment. Aberrations are measured for each bandwidth using the image height Y = 18.6 for (a) and Y = 5 for (b). As is clear from Figure 4, aberrations are corrected very well by the reflective-refractive optical system of the present embodiment.

As described, the present invention can provide a catadioptric lens system whose entire size is practically compact and is capable of providing a large numerical aperture in the ultraviolet band. The invention also provides photolithographic resolution of quarter micron levels and is easy to manufacture.

## Claims

1. A catadioptric lens system characterized by the fact that said catadioptric lens system comprises:

- a) a first lens system constructed with refractive members,
- b) a concave mirror, and
- c) a second lens system including refractive members to project a semiconductor device pattern from a reticle surface onto a substrate wherein at least said first lens system includes one or more aspherical surface(s) which point to the reticle surface.

2. The catadioptric lens system of claim 1, wherein said first lens system comprises:

- a) a first lens group having a plurality of lenses in which light enters only once; and
- b) a second lens group having a plurality of lenses through which the light exiting from said first lens group makes a round trip with the second lens group including a negative lens located at a position closest to the concave mirror such that the light coming through said second lens group images said semiconductor device pattern once before entering said second imaging lens system.

3. The catadioptric lens system of claim 1, wherein an optical path reflection member is arranged between said first lens system and said second lens system or in said second lens system.

4. The catadioptric lens system of claim 3 wherein said optical path reflection member is a plane mirror.

5. The catadioptric lens system of claim 1, wherein said refractive members in said first lens system and said refractive members in said second lens system are constructed from a mineral selected from the group consisting of quartz and fluorite.

6. The catadioptric lens system of claim 1, wherein said concave mirror is aspherically shaped.

7. The catadioptric lens system of claim 2, wherein an optical path reflection member is arranged between said first lens system and said second lens system.

8. The catadioptric lens system of claim 2, wherein said refractive members in said first lens system and said refractive members in said second lens system are constructed from a mineral selected from the group consisting of quartz and fluorite.

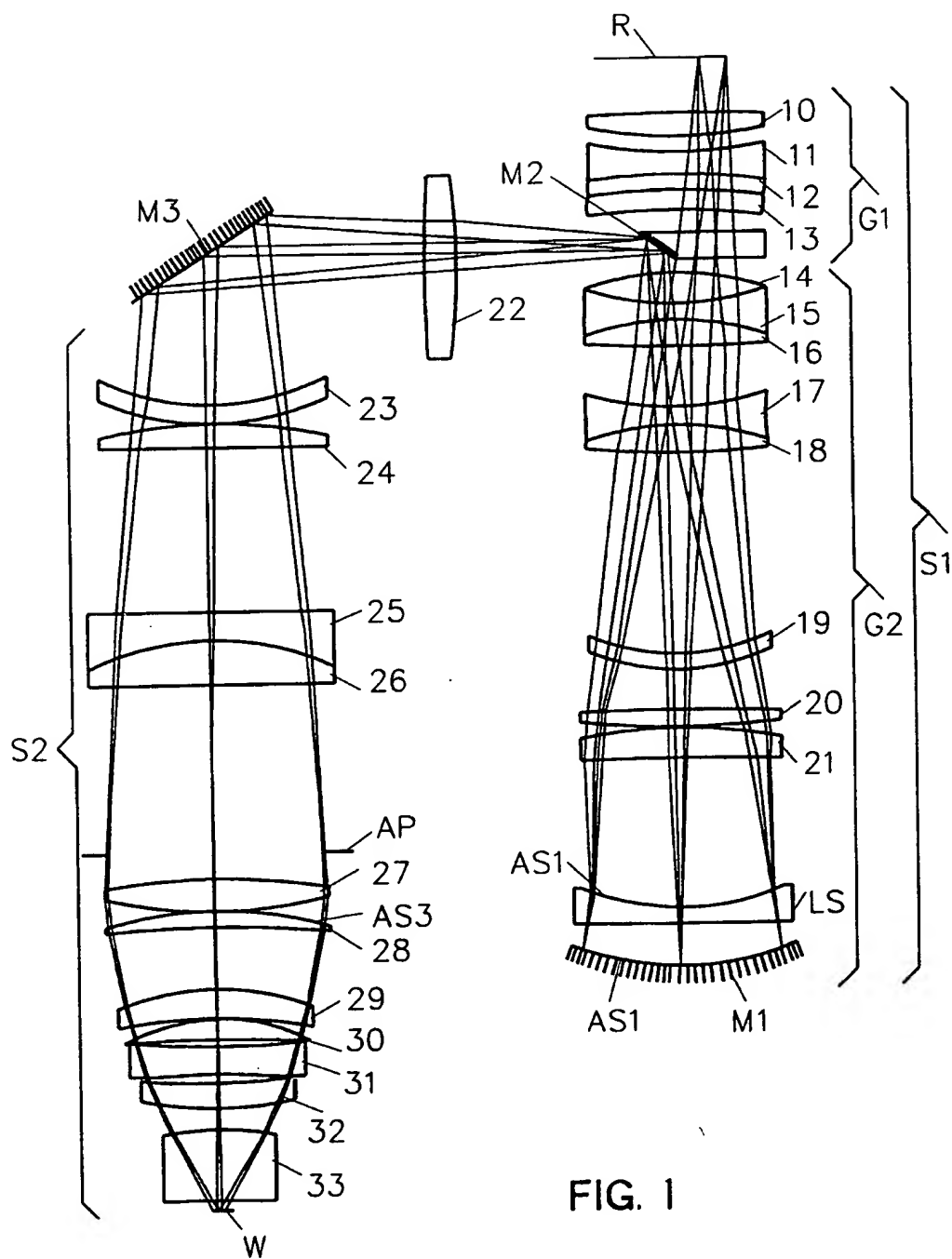
9. The catadioptric lens system of claim 3, wherein said refractive members in said first lens system and said refractive members in said second lens system are constructed from a mineral selected from the group consisting of quartz and fluorite.

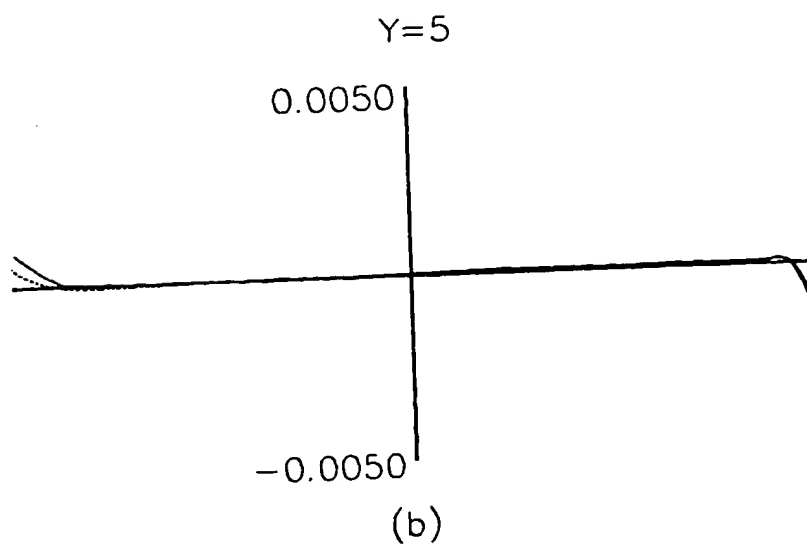
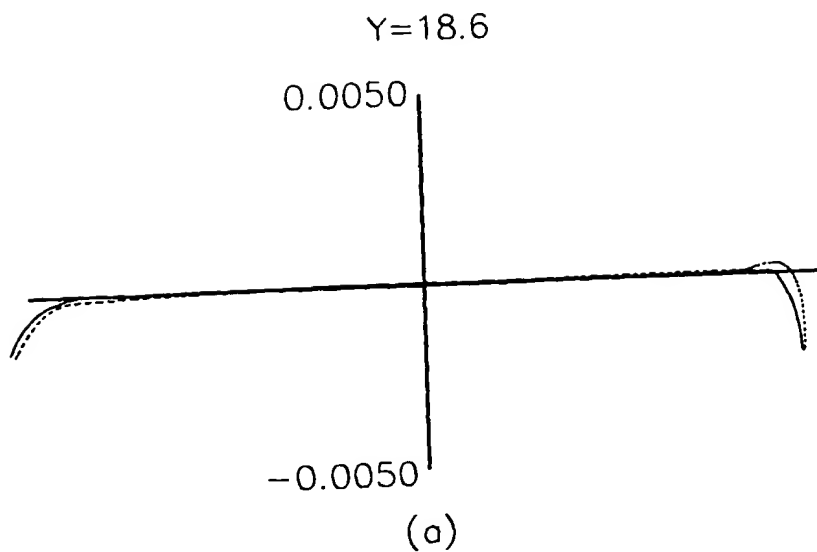
10. The catadioptric lens system of claim 2, wherein said concave mirror is aspherically shaped.

11. The catadioptric lens system of claim 3, wherein said concave mirror is aspherically shaped.

12. The catadioptric lens system of claim 5, wherein said concave mirror is aspherically shaped.

13. The catadioptric lens system of claim 10 wherein at least one of the refractive members in the first lens system has at least two different negative refractive powers and wherein another refractive member has at least two different positive refractive powers.





-----	193.8 NM
- - - - -	193.6 NM
—————	193.4 NM
- - - - -	193.2 NM
.....	193.0 NM

FIG. 2

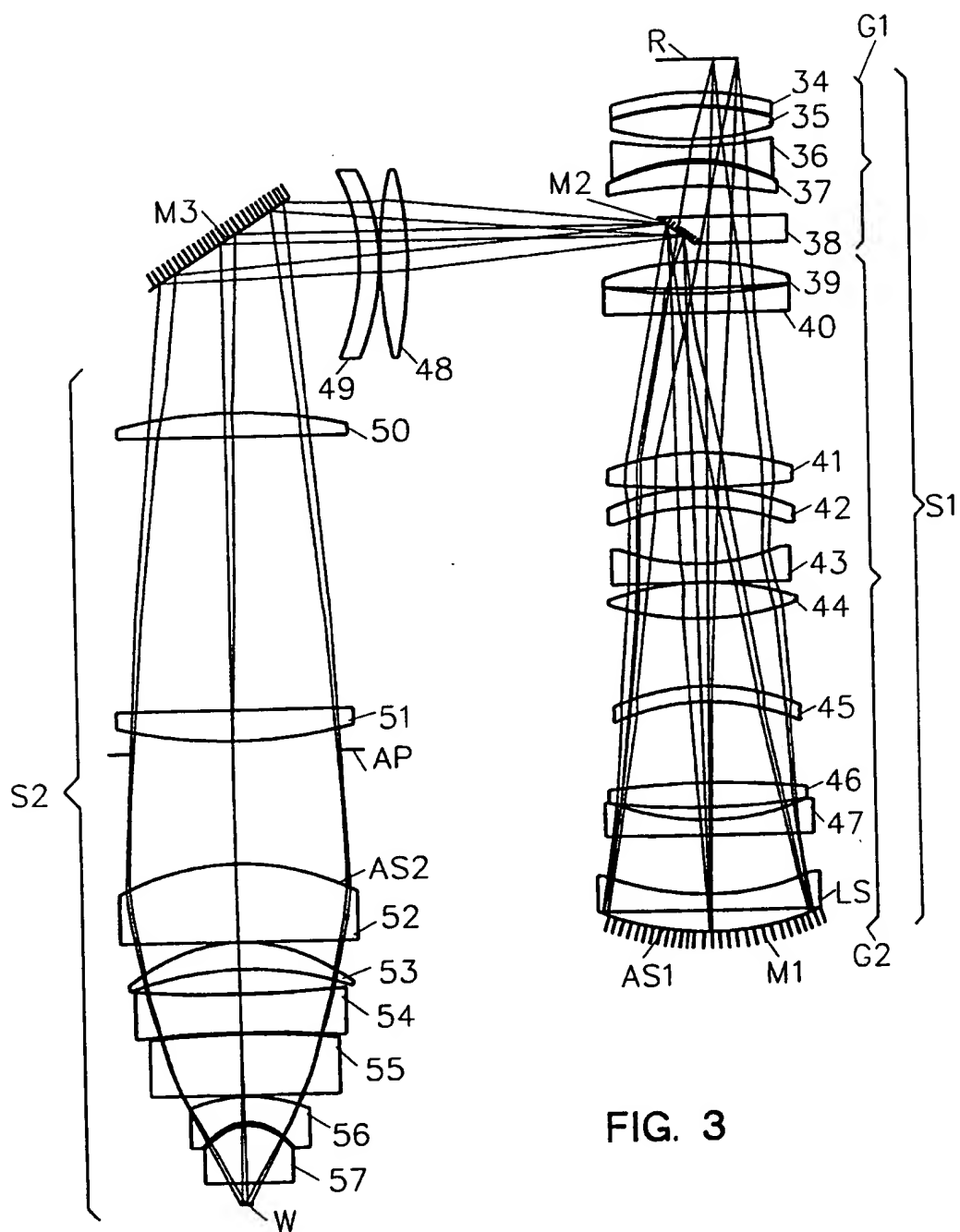
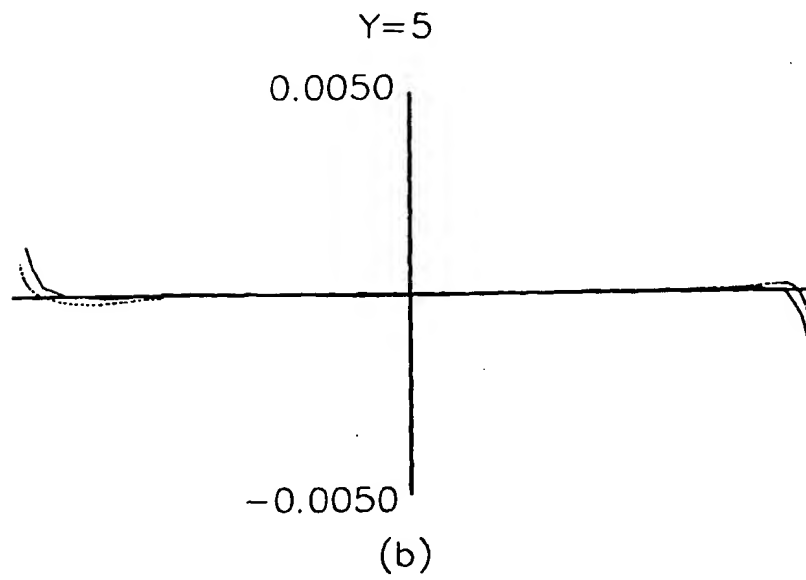
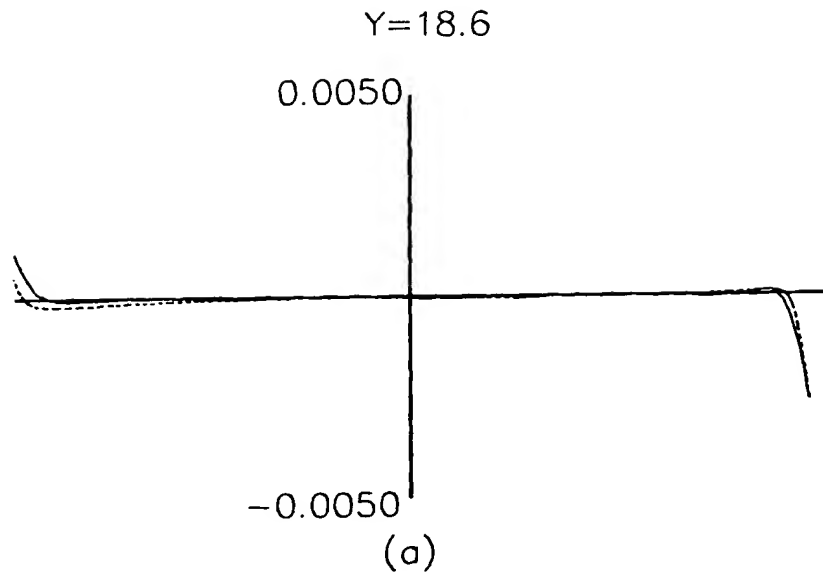


FIG. 3



-----	193.8 NM
- - - - -	193.6 NM
—————	193.4 NM
- - - - -	193.2 NM
.....	193.0 NM

FIG. 4



(19)



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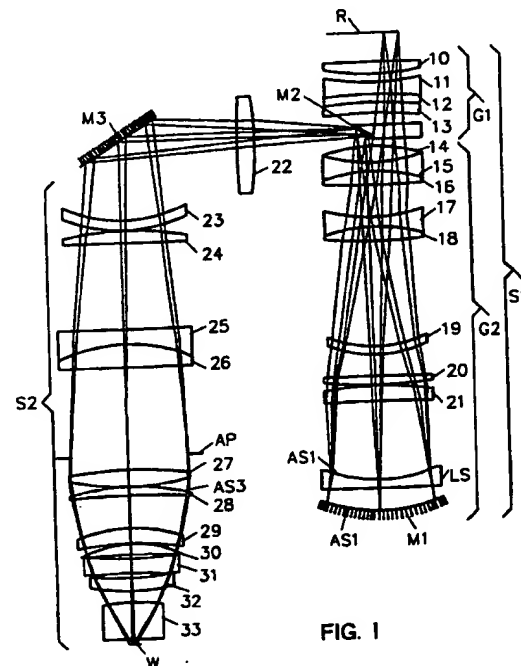
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## (54) Catadioptric lens system

(57) A catadioptric lens system whose entire size is practically compact and is capable of providing a large numerical aperture in the ultraviolet band region is disclosed. The invention also provides photolithographic resolution of quarter micron levels and is easy to manufacture. The invention comprises, a first lens system S1 constructed with refractive members, a concave mirror M1, and a second lens system S2 constructed with refractive members to project a semiconductor device pattern from a reticle surface onto a substrate wherein at least said first lens system includes one or more aspherical surface(s) which point to the reticle surface.



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# EUROPEAN SEARCH REPORT

Application Number  
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A	EP 0 527 043 A (NIPPON KOGAKU KK) 10 February 1993 * page 3, line 50 - page 7, line 46; figure 2 *	1-13	
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Place of search THE HAGUE		Date of completion of the search 20 April 1999	Examiner THEOPISTOU, P
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